CRC-8 firmware implementations for SMBus

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Scope

- CRC-8 has been defined as optional feature of SMBus V1.1
- Packet Error Checking will improve the reliability of the bus
- Let’s make sure that we understand it the same way

CRC's basic idea

- The remainder of a division changes a lot with small changes in the dividend

```
                    ..0000001101 = Quotient
1001                  0001100001 = Dividend
Divisor               0001,.. .,
                      0000,.. .,
                       0011.. .,
                       0000.. .,
                        0110. .,
                        0000. .,
                         1100 .,
                         1001 .,
                          1010.,
                          1001.,
                           0110,
                           0000,
                            1100
                            1001
                             101
```

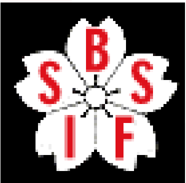
Polynomial arithmetic mod 2

- No propagation of carry
- Addition AND subtraction are performed with XOR
- Multiplication is similar with binary except that sums are calculated with XORs
- Division relies on “weak” definition of larger or equal
  - X is greater than or equal to Y if and only if the position of the highest 1 bit of X is the same or greater of the highest 1 bit of Y

SBS IF DevCon Japan 1999

CRC calculation

- We need the following:
  - A polynomial of width M (divisor). In the case of SMBus, the polynomial will be using is X8 + X2 + X + 1. The width of this polynomial is 8 (the highest power of X indicates the width) and it can be represented as 1 0000 0111. Since the width of the polynomial is 8 we refer to our CRC method as CRC-8.
  - A message represented as a bit-stream augmented with M = 8 zeroes at the end.
  - Division of the augmented bit-stream message by the polynomial 0000 0111. The remainder will be the CRC-8 check byte.



CRC calculation example

- Our polynomial is: 10000 0111.
  The original message is : 0101 1100.
  After we augment it with 8 zeroes it becomes: 0101 1100 0000 0000
  We ignore the quotient as it is not used in the CRC calculation.

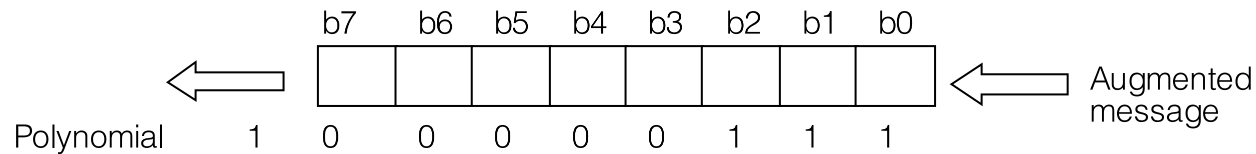
```
0101110000000000 =CRC
 100000111         XOR polynomial
 001110111000000 =CRC
   100000111       XOR polynomial
   0110110110000 =CRC
    100000111      XOR polynomial
    010110001000 =CRC
     100000111     XOR polynomial
     0011001010 0 =CRC
       100000111 XOR polynomial
```

- 010010011 =CRC

What to do with CRC

- The original message can be appended with the calculated CRC-8 byte and transmitted to the receiver.
  - The CRC-8 enhanced message will be 0101 1100 10010011.
- The receiver can perform the same calculation upon the first 8 bits of the original message and then compare the result with the received CRC-8
- Or calculate the CRC-8 upon the whole (16 bits in this example) message, without appending zeroes and verify that the outcome is zero.

The algorithm for the example



- Initialize the shift register with zeroes
- Shift left the augmented message until a 1 comes out
- XOR the contents of the register with the low eight bits of the polynomial
- Continue until the whole message has passed through the shift register (the trailing zero bits will be the last ones to fill the register and their role is to push out the original message)
- The CRC-8 is the last value of the shift register

- Calculator Example

Implementation problems

- Easier to implement in hardware
- In real communication systems including SMBus you may not want to put the calculation load at the end
  - It takes long time
  - You need to respond fast with ACK, NACK
- How can you perform the calculation byte by byte?

Back to arithmetic...

- What we need is A/B = Q + R
- In CRC we are interested in only on the remainder so we can re-write our expression as A/B => R
- If we express A = A1 + A2 then our task would be described as
  - (A1+A2)/B =>R
  - or A1/B + A2/B = (Q1 + R1/B) + A2/B
  - or Q1 + (R1 + A2)/B =>R

Two different methods

Straightforward

```
01011000000 =CRC
 11010         XOR with polynomial in 2nd position
 01100000000 =CRC
  11010         XOR with polynomial in 3rd position
  0001000000 =CRC
     11010     XOR with polynomial in 6th position
     0101000 =CRC
      11010  XOR with polynomial in 7th position
      011100 =CRC
       11010 XOR with polynomial in 8th position

       00110 =CRC
```

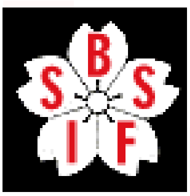
Breaking the message into a sum

```
01010000 =CRC
 11010        XOR with polynomial(2nd position)
 0111000 =CRC
  11010         XOR with polynomial(3rd position)
  001100 =CRC (completed calculation with first number)
    10000000  Add (XOR) now the remainder to the second nibble
    01000000 =CRC
     11010   XOR with polynomial(6th position)
     0101000 =CRC
      11010 XOR with polynomial(7th position)
      011100 =CRC
       11010 XOR with polynomial (8th position)
       00110 = CRC
```

Interesting observations

- We can use the CRC value derived from the first nibble and add it (XOR) to the second nibble in order to continue the calculation
- The XORs of the dividend with the polynomial occur in the same bit positions
- If we XOR the polynomial shifted into these positions we will derive the original bit-stream augmented with the CRC as it is shown below

```
_11010
__11010
_____11010
______11010
_______11010
------------
010110000110
```



1st method - Direct

- Initialize the CRC register with zeroes
- Perform the straightforward algorithm (bit by bit) on the first byte augmented by 8 zeroes
- XOR the CRC with the next byte and calculate again with the straightforward method
- Until the whole message is passed through the calculation

Direct method sample code

```
* This code calculates a new CRC value for each byte received
* Registers used:
*           Accumulator    A
*           Index          X
*           Memory register    CRC
*           Memory register    temp
*
* Input:        Memory register CRC contains the previously calculated CRC value -
initialized to zero
*               Accumulator    A contains the next input data byte
* Output:       Memory register CRC contains the current CRC value
```

- Minimum overhead to enter: [6] (jump to subroutine call)
- [x] denotes machine cycles for each instruction

```
init_crc:
    ldx #8      [2] ;initialize x-register with the # of bits to be shifted
    eor CRC     [4] ; X-OR new byte with contents of memory location CRC in order to obtain
(remainder + next incoming byte)
crc_loop:
* start the straightforward approach
    rola        [3] ; rotate left and place the MSB into the Carry
* rola operation fills the empty bits with zeroes
    bcc zero    [3] ; if carry is clear no need to do anything, continue
    eor #$07    [2] ; else, perform the X-OR of CRC with the polynomial
zero:
    decx        [3] ; decrement bit counter
    bne crc_loop [3]   ; if more bits need to be processed repeat the loop
    sta CRC     [5] ; save the new CRC value
return:
    rts         [6] ; no more bits, return from subroutine
```

Direct method performance

Fosc	Execution time for one byte	Overhead for "5 bytes" protocols Msg Transfer Time* = 1.5 ms	Overhead for "35 bytes" protocols Msg transfer time = 10.5 ms
4 MHz	68us	340 us	2.36 ms
2 MHz	135 us	680 ms	4.75 ms
1 MHz	270 us	1.35 ms	9.45 ms
600 KHz	450 us	2.25 ms	15.75 sec

Machine cycles required = 135
SM Bus operates at 30KHz

Recall

- All it matters is the positions of the polynomial when shifted
- We know the positions if we know the data byte
- We can ADD (XOR) the CRC of the first byte with the next incoming byte
- All we need is a table
- Calculator example

2nd method- 256 lookup table

- Initialize the CRC register to 0
- XOR each incoming byte with the previous CRC value (Add the remainder of the previous division with the new value). The result is the new byte that we need to calculate the CRC value (or remainder of the division)
- Use this value as the index to the table to obtain the new remainder
- Continue until you have passed all bytes through the process
- The last byte retrieved from the table is the final CRC value

Code example

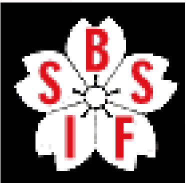
```
* This code performs a table lookup to determine the new CRC value for each byte received
* Registers used:
*            Accumulator         A
*            Memory register     CRC
*
* Input:        Memory register CRC contains the previously calculated CRC value
*               Accumulator     A contains the input data byte
* Output:       Memory register CRC contains the current CRC value
get_crc:
    eor CRC          [4]     ; X-OR the received byte with the stored CRC value (result in
ACC)
    tax              [2]     ; no need to pay taxes yet... just transfer ACC to X register
    lda table,x      [5]     ; load the new CRC value from the lookup table
    sta CRC          [4]     ; save the new CRC value
*
```

Calculator example

2nd method performance

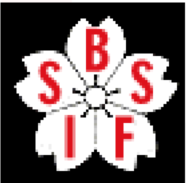
Fosc	Execution time for one byte	Overhead for "5 bytes" protocols Msg Transfer Time* = 1.5 ms	Overhead for "35 bytes" protocols Msg transfer time = 10.5 ms
4 MHz	7.5 us	37.5 us	262 us
2 MHz	15 us	75 us	525 us
1 MHz	30 us	150 us	1 ms
600 KHz	50 us	250 us	1.75 ms

Machine cycles required = 15



Working with nibbles

- The same method can be applied to nibbles instead of bytes
- Results in a much smaller table (16 bytes)
- Good for 4-bit MCUs
- A lot of shifts for 8-bit MCUs
- But it saves ROM space and it is faster than the direct method calculation
  - Calculator example



Performance

Fosc	Execution time for one byte (us)	Overhead for "5 bytes" protocols Msg Transfer Time* = 1.5 ms	Overhead for "35 bytes" protocols Msg transfer time = 10.5 ms
4 MHz	45	225 us	1575 us
2 MHz	90	450 us	3150 us
1 MHz	180	900 us	6300 us
600 KHz	300	1500 us	10500 us

Machine cycles required = 90

Improved 32 byte table lookup

- We can eliminate some of the shifts by creating a second 16 byte table with reversed nibbles
- Example
  - 07 -> 70
- Improves performance in 8-bit MCUs

32 byte table performance

Fosc	Execution time for one byte (us)	Overhead for “5 bytes” protocols Msg Transfer Time* = 1.5 ms	Overhead for “35 bytes” protocols Msg transfer time = 10.5 ms
4 MHz	30	150 us	1050 us
2 MHz	60	300 us	2100 us
1 MHz	120	600 us	4200 us
600 KHz	199	995 us	6965 us

Machine cycles required = 60

CRC-8 polynomial

- Polynomial: X8+X2+X1+X0
- It will detect all single bit errors
- All Odd number of bit errors
- Any burst error less than 8 bits long
- Most of other type of errors

Conclusions

- By understanding the CRC principles algorithms can be devised to address any speed/space condition
- It is important for the CRC-8 results to agree
- The CRC calculator will be made available along with the source code at www.usar.com
- CRC-8 calculator and white paper available for download from USAR's web-site